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MULTIPLE CHOLESTERIC LIQUID CRYSTAL OPTICAL COATINGS					
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Multiple Cholesteric Liquid Crystal Optical Coatings

Background of Invention:

The bistable cholesteric reflective display technology was introduced in the early 1990s as a low power, sunlight readable technology intended primarily for use on handheld or portable devices. Such devices often demand long battery lifetimes requiring the display to consume very little power. Cholesteric displays are ideal for this application as the bistability feature avoids refreshing power and high reflectivity avoids the need of power-consuming backlights. These combined features can extend battery life times from hours to months over displays that do not have these features. Cholesteric reflectivity has another extremely useful feature that allows very bright full color reflective displays: They make use of all available ambient light in reflecting all colors. This feature is not held by traditional displays where the display is broken into pixels of different colors. Using all available light is important observing a reflective display in a dimly lit room without a backlight. Reflective displays are also easily read in very bright sunlight where backlit displays are ineffective. The wide view angle offered by a cholesteric display allows several persons to see the display at the same time.

Cholesteric liquid crystalline materials are unique in their optical and electro-optical features. Of principal significance, they can be tailored to Bragg reflect light at a pre-selected wavelength and bandwidth. The feature comes about because these materials possess a helical structure in which the liquid crystal (LC) director twists around a helical axis. The distance over which the director rotates 360° is referred to as the pitch and is denoted by P . The reflection band of a cholesteric liquid crystal is located at the wavelength, $\lambda_0 = 0.5(n_e + n_o)$ and has the bandwidth, $\Delta\lambda = (n_e - n_o)P$ which is usually about 100 nm, where n_e and n_o are the extra-ordinary and ordinary refractive indices of the LC, respectively. The reflected light is circularly polarized with the same handedness as the helical structure of the LC. If the incident light is not polarized, it will be decomposed into two circular polarized components with opposite handedness and one of the components reflected.

The cholesteric material can be electrically switched to either one of two textures, planar or focal conic. In the planar texture the helix is oriented perpendicular to the substrate to Bragg reflect light in a selected wavelength band whereas in the focal conic texture it is oriented parallel to the substrate so that the material is transparent to all wavelengths. These bistable structures can be electronically switched between each other at rapid rates (on the order of milliseconds). Gray scale is also available in that only a portion of a pixel can be switched to the reflective state.

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By: Robert M. Dwyer

Bistable cholesteric liquid crystal displays have several important electronic drive features that other bistable reflective technologies do not. Of extreme importance for addressing matrix display of many pixels is the characteristic of a voltage threshold. A threshold is essential for multiplexing a row/column matrix without the need of an expensive active matrix (transistor at each pixel). Another important feature of cholesteric materials is that the RGB colors as well as IR nightvision can be stacked (layered) on top of each other without optically interfering with each other. This makes maximum use of the display surface for reflection and hence brightness. Because a cholesteric display cell does not require polarizers, low cost birefringence plastic substrates such as PET can be used. Other features, such as wide viewing-angles and wide operating temperature ranges as well as fast response times make the cholesteric technology the bistable reflective technology of choice for many applications.

Today cholesteric displays are manufactured and sold on glass substrates; the cholesteric fluid material being sandwiched between two pieces of glass. A monochrome display, with one reflective color on a black or different colored background, is manufactured in this way. Bistability with a voltage threshold allows very high-resolution displays to be produced with low-cost passive matrix technology. Gray scale capability allows stacked RGB, high-resolution displays with full-color capability where as many as 4096 colors have been demonstrated.

In the display community there has been an interest in manufacturing displays on flexible substrates such as plastic. Such displays offer the possibility of lower cost roll-to-roll manufacturing in addition to lighter weight, more rugged and conformable or flexible displays. In order to accommodate such manufacturing, it is important that the cholesteric materials can be coated or printed onto the flexible substrate. It is further useful if the materials are self-sealing so that cholesteric liquid does not flow from between the substrates. Incorporating encapsulated liquid crystals satisfies both of these requirements.

There are many different approaches to encapsulation, some of which have been used for cholesteric liquid crystals. One such process is phase separation, which is basically a process that involves mixing the cholesteric liquid crystalline material with a pre-polymer solution then polymerization under suitable conditions to form a dispersion of droplets in a polymer binder. Polymerization and hence droplet formation occurs after the material mixture has been coated. There are basically three types of polymerization techniques that can be used depending on the polymer (or monomer): (1) thermally induced phase separation (TIPS); (2) polymerization induced phase separation (PIPS); and, (3) solvent induced phase separation (SIPS).

The thermally induced phase separation (TIPS) process has been used to show that a cholesteric material will maintain its bistability and electro-optical features when encapsulated into a droplet structure [US Patent 6,061,107]. The TIPS system is a binary mixture of a liquid crystal and a thermoplastic (polymer). The mixing interaction energy is positive. At high temperature, the mixing entropy term is large and dominant; the system is in a homogeneous form, which has a lower free energy. As temperature is

lowered, the mixing entropy becomes smaller, and the liquid crystal phase separates to form droplets in order to reduce the total free energy. The droplet size can be controlled by the cooling rate with smaller droplets being formed at faster cooling rates. TIPS is advantageous in controlling droplet size because cooling rates are easily adjusted. Furthermore, the system can be thermally cycled many times and different droplet sizes can be obtained in the same sample using different cooling rates. There are many thermoplastic polymers that can be used for this process. Some examples are PMMA (poly methyl methacrylate), which provides a tangential anchoring condition and PIMB (poly isobutyl methacrylate), which provides a perpendicular anchoring condition.

Polymerization induced phase separation (PIPS) starts with a homogeneous mixture of a prepolymer (monomer) and a liquid crystal. As the monomers are polymerized, the number of possible configurations of the monomers decreases and thus the mixing entropy decreases. When the degree of polymerization reaches a critical value, the liquid crystal phase separates from the polymer. The polymerization can be thermalinitiated or photo-initiated. In thermal-initiated polymerization, the monomers are typically combinations of epoxy resins and curing agent thiol, such as Epon 828 (Shell Chemical) or Capcure 3800 (Miller Stephenson Company). The mixture coated at room temperature can then be cured at an elevated temperature. Smaller droplets are formed at higher temperatures or higher concentrations of epoxy resins because of the higher reaction rate.

In photo-polymerization, monomers with acrylate or methacrylate end groups, such as Norland 65 (which is a combination of acrylate monomers and photo-initiators), are used. Some photo-initiators are also needed. Upon absorbing a photon, the photo-initiator becomes a free radical, which reacts with the acrylate group and results in an opened double bond. The opened double bond reacts with another acrylate group. The chain reaction propagates until the opened double bond reacts with another opened double bond or another free radical, and then the polymerization stops. In sample preparation, the mixture is printed or coated then cured under the irradiation of uv light. Smaller droplets are formed under higher uv irradiation.

In the SIPS method, the initial material is a mixture of a liquid crystal and a thermoplastic dissolved in a common solvent. When the concentration of the solvent is sufficiently high, the mixing interaction energy of the system is negative, and the components are homogeneously mixed. As the solvent evaporates, the mixing interaction energy increases. At a sufficiently low concentration of the solvent, the system phase separates to reduce the mixing interaction energy. The droplet size of the liquid crystal depends on the solvent evaporation rate with smaller droplets obtained at faster evaporation rates.

Another very different encapsulation process involves emulsification of a cholesteric liquid crystal in water with a waterborne polymer. Encapsulation of cholesteric liquid crystals by emulsification was practiced even before the invention of bistable cholesteric displays. As early as 1970, cholesteric materials were emulsified for making cholesteric thermal and electrical responsive coatings [US Patent 3,600,060]. More recently, emulsification methods have been refined to making cholesteric droplets that are very uniform size [US Patent 6,423,368 B1]. The most common emulsification procedure

basically involves a liquid crystal being dispersed in an aqueous bath containing a water-soluble binder material such as de-ionized gelatin, polyvinyl alcohol (PVA) or polyethylene oxide (PEO). Water acts as a solvent and dissolves the polymer to form a viscous solution. This aqueous solution does not dissolve the liquid crystal, and they phase separate. When a propeller blade at a sufficiently high speed stirs this system, the micron size liquid crystal droplets are formed. Smaller liquid crystal droplets form at higher stirring speeds [P. Drzaic, *Liquid Crystal Dispersions*, World Scientific Publishing Co., Singapore (1995)]. The molecular weight of the water-soluble polymer is also a factor affecting the droplet size. Larger droplets form with lower molecular weight. After the droplets are formed, the emulsion is coated on a substrate and the water is allowed to evaporate. There are many different emulsification procedures; however, the one primarily followed for liquid crystalline materials is basically the process described above using PVA. The emulsification method has the advantage that the droplet dispersions may contain a very high percentage of cholesteric material.

Recently, it has become more important to make brighter, more contrasting reflective displays as well as multiple color displays on flexible substrates. In order to produce brighter displays, it is necessary to stack cholesteric layers of left- and right-handedness. Stacking cholesteric layers of different reflective color also makes multiple color displays. It is therefore necessary to layer cholesteric materials with different optical properties on top of one another. In order to avoid mixing the different cholesteric materials and therefore destroying their optical properties, it is necessary to separate them in a manner that the different liquid crystal materials cannot diffuse or flow into each other. One method to avoid this is to incorporate a substrate or similar laminated barrier between them; however, this reduces the flexibility of the display and makes it too thick as the various layers are added.

Reflection from droplet structures needs to be carefully examined to look at the degree of circularly polarized light. This is because the degree of circular polarization indicates the amount of light that will be used in a multi layer system where both left and right handed twist sense liquid crystalline mixtures are being used [see Khan et al. US 6,532,052]. The degree of circularly polarized light can be measured through the measurement of the Stokes parameter, S_3 . This is the vertical axis on the Poincaré sphere representation of polarized light. A value of +1 for S_3 is for completely right circularly polarized light. A value of -1 for S_3 is for completely left circularly polarized light. A value of 0 for S_3 signifies no circularly or elliptically polarized components (linear polarization). Clearly, high values of S_3 are desirable so as to get high brightness.

High values of S_3 typically come from textures that have narrow viewing angles. As such, usually a compromise needs to be made between the viewing angle and the brightness. The droplet shape may be modified to make such adjustments. As will be described in this disclosure, smaller spherical droplets can make very wide view angle films whereas large non-spherical droplets may be used to increase the value of S_3 . As will be shown and discussed, a combination of the two may be done in the same layer or in multiple layers to modify the optics of the multiple layer system.

Polymer networks can also be used to increase the viewing angle, broaden the reflection spectrum, and change the value of S_3 for the reflected light. This can be done to a degree where the reflection from the planar texture of a cholesteric material may look achromatic or white [see Yang et al. US 5,847,798]. As such, similar techniques can be applied to material inside a droplet or simply from the droplet shape.

In this invention disclosure we describe methods and materials for accommodating multiple coatings on top of one another. Unique combinations of different encapsulations processes and/or droplet dispersions are described that permit cholesteric materials with different optical properties to be coated directly on top of one another offering an effective barrier to molecular diffusion. Where an additional barrier is needed, the encapsulated layers may be made rugged and of uniform thickness so that a thin inner layer maybe coated or laminated on top of the first encapsulation layer before a second encapsulation layer is coated or laminated. This invention advances the cholesteric technology to take advantage of its stacking ability for high brightness, wide view angle, and multiple color capabilities.

Description of Invention:

Disclosure Summary

Accordingly, the invention discloses a variety of unique combinations of different encapsulant materials and processes to permit a cholesteric material with one optical property to be coated on top of another cholesteric material with a different optical property.

We disclose a method and materials for coating cholesteric liquid crystalline materials with different optical properties on top of one another whereby the different materials do not mix for an extended period of time sufficient for use in optical devices such as flat-panel displays.

We disclose a method and material for coating one cholesteric material on top of another in which one of the materials is encapsulated by emulsification methods using a waterborne (hydrophilic) polymer and the other material is encapsulated by a phase separation methods using a hydrophobic polymer whereby the two encapsulated cholesteric materials do not mix when coated on top of one another and the hydrophilic/hydrophobic combination offers a sufficient barrier to molecular diffusion to maintain the different optical properties of each of the two layers for extended periods of time.

We disclose a method and materials for coating one cholesteric material on top of another in which one of the materials is encapsulated by emulsification methods using a waterborne (hydrophilic) polymer and the other material is encapsulated by emulsification in a hydrophobic polymer whereby the two encapsulated cholesteric materials do not mix when coated on top of one another and offer a barrier to molecular diffusion.

We disclose multiple coatings with alternating coatings involving hydrophilic and hydrophobic polymer encapsulants.

We disclose multiple coatings of emulsion dispersions where alternate layers are from, first an emulsion with water borne colloids which become water insoluble after drying, and second, from an emulsion with water-soluble polymer-binder on top of the first layer. The emulsions with water borne polymer can be stacked in any number.

We disclose methods of multiple coatings whereby two phase separated cholesteric droplet dispersions involving different cholesteric materials can be coated on top of one another such that the two material materials do not physically mix upon coating.

We disclose methods and materials whereby two encapsulated cholesteric materials or cholesteric droplet dispersions with hydrophobic polymers can be coated on top of one another with a hydrophilic barrier coated or laminated material in between.

We disclose a method and materials whereby a cholesteric liquid crystalline material with left or right hand twist can be coated on top of another cholesteric material with an opposite handed twist providing a bistable cholesteric display with enhanced brightness.

We disclose a method and materials whereby two optically different cholesteric liquid crystalline materials are prepared separately and then laminated together using a heated lamination and/or a pressure lamination.

We disclose a method and materials where by a cholesteric liquid crystalline material with a particular reflective color be coated on top of another cholesteric material with a different reflective color so that the materials can optically function independent of one another and the reflective colors additively mixed to yield another reflective color.

We disclose a method and materials whereby there may be multiple coatings involving cholesteric liquid crystalline materials with different twist handedness and different reflective colors to create reflective displays with unique brightness, angle of view and color properties.

We disclose a method of producing multiple coatings of cholesteric materials on flexible substrates providing reflective cholesteric displays with improved flexibility and ruggedness.

Summary of Invention:

Emulsion/Phase Separation

In order to maximize the brightness of a cholesteric display, it is necessary to reflect both the left and right circular components of the incident light. There are two methods to accomplish this: To layer a cholesteric material of one handedness on top of the other or to insert a half wave plate in between two layers of the same handedness. This invention involves the former whereby the cholesteric materials of different handedness are coated on top of one another. A display cell with coated left and right layers is illustrated in Fig.

1. The coatings must be immiscible so that the droplet structures of the two different materials are not destroyed in the coating or drying process. Furthermore, the encapsulant surrounding the droplets must be impermeable to the cholesteric material to limit molecular diffusion in that cholesteric material of one handedness dissolving into the other will destroy its desired optical properties.

We have invented means to accomplish both of these requirements by coating a cholesteric liquid crystal of one handedness encapsulated in a hydrophilic polymer such as PVA. In the preferred method this encapsulated material is first coated onto the substrate. We then coat a second cholesteric liquid crystal with the other handedness dissolved in a pre-polymeric hydrophobic material on top of the first encapsulated coating. The hydrophobic material in the upper coating and hydrophilic material in the lower layer prevent one layer from dissolving into the other. The polymer in the upper layer is then polymerized whereby phase separation processes form a dispersion of liquid crystal droplets in the upper coating creating stacked coating of droplets of one handedness immediately on top of the other. We have discovered that the hydrophilic encapsulant in the first coating is strongly impermeable to hydrophilic upper material even before the polymer in the upper layer is cured. Stable coatings with long suitable lifetimes are achievable with this process.

The phase separated hydrophobic dispersion could be coated first and polymerized with the hydrophilic material coated second. The order in which the layers are coated can depend upon the phase separation process and encapsulant materials used. This process is amenable to the PIPS, TIPS and SIPS processes. In some cases, it may be desirable to add spacers to the pre-polymer/cholesteric solution to insure the proper thickness of the material.

EXAMPLE 1:

The following is an example of preparation of double layered coating comprised of a layer of encapsulated cholesteric liquid crystal (CLC) in polymer binder deposited from a water-based emulsion and a layer of encapsulated CLC produced as a result of a PIPS process after the coating deposition.

The oil-in-water emulsion was prepared from two immiscible liquids. Oil phase can be cholesteric liquid crystals with different handedness and pitch length. Water phase comprised a mixture of water-soluble polymers such as polyvinyl alcohols and its cross-linking agents. Introduction of monohydric alcohols in the water phase, such as ethanol, methanol, and isopropanol resulted in reduction of surface tension and in imposing strong anchoring boundary condition for the director at the LC/water interface.

To prepare the emulsion, typically 0.350 g of CLC, 0.250 g of 20% PVA aqueous solution, and 0.100 g of monohydric alcohol were emulsified with a homogenizer (PowerGen 700) at 1500 rpm for 3-4 min at room temperature. Encapsulating material, PVA (Celveol 205 with an 88 % hydrolization, from Celanese Chemicals) was initially purified using Soxhlet extraction method. Emulsified CLC formed droplets which are about 2-10 μm in diameter. Cross-linking agents, such as glyturaldehyde or others can be added to the solution to cross link the polymer and create impermeable polymer walls

around encapsulated CLC. Concentration of cross linkers typically was 1-3 % of a polymer weight. By changing the composition of the emulsion and stirring rate, the droplets with larger sizes of 15-35 μm can be obtained. Emulsions of CLC droplets in aqueous phase were stable at least over two months period.

After degassing for 2 hours the emulsion can be deposited onto an electrode-coated substrate using bird doctor blade technique followed by drying at room temperature for 60 min. The electrode coated substrates were polycarbonate and PET films with thickness of 100 and 200 μm .

A second coating may be applied on the top of the first encapsulated layer and laminated with a top electrode coated substrate using a roll laminator. The second layer consist of a mixture of CLC and one of the UV curable optical adhesives, such as NOA 65, 68, 72, and 81 (From Norland Inc.). The mixture composition was 55-70% of CLC and 45-30% of the optical adhesive. The 0.1 % by weight of 6.5 μm plastic spacers was added to the mixture to control the layer thickness. Phase separation and polymerization in the second coated layer was obtained by exposure to UV lamp with intensity of several milliwatts per square centimeter for 4 min. Typical size of the encapsulated CLC droplets was in the range of 20-40 μm .

Two sets of double layered coating were prepared to test impermeability of the layers. First double layer coating consists of the emulsion layer with right handed CLC and PIPS layer with left handed CLC. Second double layer coating is similar to the first one, except that two CLC have different pitch lengths and Bragg reflect in the different range of the visible spectrum. The cycling switching over 6 week period shows no sign of mixing the CLC between two layers.

EXAMPLE 2:

The following is an example of preparation of double layered coating comprised of a layer of encapsulated CLC in polymer binder deposited from water-based emulsion and a layer of encapsulated CLC produced as a result of a TIPS process after the coating deposition. The emulsion layer was prepared according to the procedure described in Example 1. The TIPS material consisting of 30 % by weight solution of mixture of PEMA (10%) and CLC (90%) in chloroform was pipetted on the electrode coated substrate with previously deposited a hard coat with imbedded 6.5 μm spacers. After heating to 85°C for 1 hour the layer was put on the top of the first emulsion coating covered by a 2.5 μm Mylar film to create a thin inner-layer and pressed with a bladder press at 80°C for 2 hours. The membrane was used to prevent possible mixing in the isotropic state at elevated temperatures. To initiate the TIPS process, the coating underwent the slow cooling to ~ 50°C with a rate of 0.5 degree/min

Emulsion/Emulsion

The coating of one emulsion on top of the other requires the use of materials whereby the second coating does not rupture the droplets or otherwise destroy first coating. It is desired that the coated liquid slurry of the second coating be immiscible with that of the

first. This is accomplished by use of latex binders or latex in combination with PVA binders.

EXAMPLE 3:

The following is an example of preparation of double layered coating comprised of a layer of encapsulated CLC in latex binder deposited from a water-based emulsion and a layer of encapsulated CLC in PVA binder deposited from a water-based emulsion on the top of first layer. The latex emulsion was prepared by mixing CLC with Neorez 967 (from Neoresins, Inc.) containing 40% of latex solids by weight with a homogenizer (PowrGen 700) at 1500 rpm for 3-4 min at room temperature. The ratio between CLC and latex solids by weight is in the range of from 3:1 to 1:1. After degassing for 2 hours the emulsion was deposited onto an electrode-coated substrate using bird doctor blade technique followed by drying at room temperature for a couple hours. Typical size of the encapsulated CLC droplets was in the range of 8-50 μm . The second layer was coated on the top this layer using a doctor blade. Second layer can be either PVA-based emulsion prepared according with procedure described in Example 1 or another latex-based emulsion. Second layer can comprised of CLC with different handiness and pith length in comparison with CLC in the first layer.

Phase Separation/Phase Separation

Phase separated droplet dispersions may be coated on top of one another provided the polymer encapsulant of the first coating is either cross-linked or is otherwise immiscible in the liquid of the second coating. In this process, it is also desirable that suitable droplet formation will occur in the phase separation process without the presence of an upper substrate. Special materials and/or polymerization procedures are required to prevent the liquid crystal from leaching out to the surface during the curing process.

The PIPS process is most attractive for multiple layered phase separated droplet dispersions since the resulting materials are usually cross-linked making them not only more immiscible to the upper coating, but also, more impermeable to molecular diffusion of the cholesteric liquid crystalline material. In the PIPS process, it may be necessary to incorporate ultraviolet (UV) absorbing dyes in the material so that the upper surface is cured at a fast rate than the lower surface. This can seal the layer at the top and hold the liquid crystal inside the layer during curing. In some instances this can also be accomplished by varying the rate of UV intensity on the photo curing light source. A heavy dosage initially, can seal the upper surface with subsequent slower curing to create a droplet structure of desired size.

The TIPS or SIPS may be suitable for one of the coatings or suitable for both if the thermally cured material is or can subsequently be cross-linked following droplet formation.

EXAMPLE 4:

An inner hydrophilic or other coated layer may be required to prevent molecular diffusion.

Droplet Shaping

We have found that it is possible to control the optical response of the cholesteric droplet dispersions by adjusting the shape of the droplets. Spherical droplets can introduce many defects in the cholesteric textures such as to offer a wide angle of view as well as broaden the reflective bandwidth. Flat droplets of non-spherical shape have fewer defects and provide brighter reflectivity, narrower angle of view and larger degree of circular polarized light necessary for achieving brightness enhancement from stacked left/right twist layers. If fact by controlling the how spherical or how flat the droplet is, one can control and regulate the desired optical response.

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EXAMPLE X

The following is an example of preparation of one layer coating comprised of encapsulated CLC in polymer binder deposited from a water-based emulsion. 0.35 g of cholesteric liquid crystal KLC 19 (from Merck), 0.250 g of 20% PVA solution in de-ionized water and 0.100 g of methanol were emulsified at 1500 rpm for 3 min at 30°C. The emulsion was coated with doctor blade technique onto a polycarbonate substrate (100-200 μm thickness) treated with a mixture of isopropanol and water to make the surface hydrophilic. The wet thickness was about 12-13 μm . Size of the droplets of encapsulated CLC was in the range of from 3 to 10 μm . During coating drying initially spherical droplets are slightly flattened in the direction perpendicular to the coating surface. PVA binder induces the parallel alignment of LC molecules and perpendicular alignment of the helical axis at the droplet surface. The round shape of the CLC droplets leads to reflection of incident light at any angle. The reflectance can be as high as 39 % in the peak of very broad reflection band with full width at half height (FWHH) in excess of 250 nm. The broad reflection band results in white appearance of the coating.

Multilayer Multiple Color

In order to achieve a full-color cholesteric display with high brightness, we stack the primary colors red, R, green, G, and blue, B. The same coating procedures and encapsulant materials described above for layering left & right cholesteric materials can be applied for layering cholesteric materials with R, G or B colors.

The number of layers in the stack depends on the brightness desired. With a three layer, RGB stack the reflectivity of the display would be limited to less than 50% theoretically but, practically less than about 40%. Fig. 2 shows an illustration of cholesteric reflective

display constructed with three cholesteric layers. In order to drive the display, ~~it is~~ we may ~~necessary to~~ have coated, printed or otherwise patterned electrodes in between each layer. This may be accomplished by directly printing a pair of conducting polymer electrodes or similar transparent conductor directly on the upper and lower encapsulated material or on a coated isolation or planarization coating over the encapsulated cholesteric material. Alternatively an inner layer material with patterned electrodes on each side could be laminated between each RGB layer as indicated in Fig. 2.

EXAMPLE 6:

The following describes a display that is believed to be capable of being constructed by one skilled in the art, according to the invention described in this disclosure. For maximum brightness, it is necessary to include left and right twisted layers in each RGB color as illustrated in Fig. 3. A six-layer stack involves the same materials, processes and principles described above. There are no electrodes between the left/right twist stacks; however, electrodes are required on each side of the RGB double stacks.

The angle of view and brightness of the display is controlled by the cholesteric domain structure in the double left/right cholesteric layers of each of the colors. For maximum brightness we have droplets that provide large planar domains. While for wide view angle but less brightness a large number of domains are employed. Large domains can be created with flat or ellipsoidal shaped droplets while spherical droplets tend to form a large number of domains. The domain structure inside the droplet can also be controlled by the anchoring conditions at the droplet wall with homogeneous anchoring favoring large domain structures.

A combination of large droplets with large domain cholesteric texture and small droplets with small domain cholesteric texture may ~~ultimately~~ be engineered to provide both high reflectivity as well as wide viewing angle. The distribution of the large and the small domains can therefore be used to control brightness, viewing angle, as well as degree of polarization of the reflected light.

A desired combination for wide view angle and high brightness is for the lower layer to possess domains of larger size ~~that~~ ^{than} the upper layer of the other handedness.

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What is claimed is:

1. A bistable reflective display device consisting multiple coatings or laminations of microencapsulated droplet dispersions of cholesteric liquid crystalline materials each with different optical properties whereby each microencapsulated layer is coated or laminated on top of the other to form a stack with combined optical features.
2. A device as claimed in Claim 1 whereby each microencapsulated droplet dispersion layer is coated or laminated directly on top of the other without any coated or laminated isolation layer in between.
3. A device as claimed in Claim 2 whereby each layer in the stack alternates between hydrophilic and hydrophobic polymer encapsulants to avoid mixing at the coating stage and to offer a high barrier to molecular diffusion for long term stability.
4. A device as claimed in Claim 3 where the hydrophilic encapsulant is a water-based emulsion and the hydrophobic encapsulant is a polymer from a phase separated droplet dispersion.
5. A device as claimed in Claim 3 where the hydrophilic encapsulant is a water-based emulsion and the hydrophobic encapsulant is a latex-based emulsion.
- 5.1 A device as claimed in Claim 1, where each microencapsulated droplet dispersion layer is a latex based emulsion deposited such that each layer is completely dried before coating the next layer.
6. A device as claimed in Claim 1 whereby each microencapsulated droplet dispersion layer is coated or laminated on top of the other with an intermediate coated or laminated isolation layer.
7. A device as claimed in Claim 6 whereby the intermediate coated or laminated layer is a conducting polymer.
8. A device as claimed in Claim 1 where the coatings are coated on a flexible plastic substrate containing transparent conducting electrodes and with a flexible plastic substrate, containing transparent conducting electrodes laminated on top of the coatings.
9. A dual layered device as claimed in Claim 1 wherein the one layer is a dispersion of cholesteric liquid crystalline droplets of left hand twist and the other layer is a dispersion of cholesteric droplets of right hand twist.
10. A device as claimed in Claim 1 wherein the multiple layers are cholesteric liquid crystalline dispersions each of a different reflective wavelength.

11. A device as claimed in Claim 1 wherein one layer of droplet dispersions is of one twist handedness and reflective wavelength and the other layer of the opposite twist handedness and of a different reflective wavelength.
12. A bistable reflective display device consisting of a stack of dual layer coatings of microencapsulated droplet dispersions, wherein each dual layer consists of coatings droplet dispersions of cholesteric liquid crystalline materials each with different twist handedness and wherein each dual layer in the stack consists of cholesteric liquid crystalline materials of different reflective wave length.
13. A device as claimed in Claim 12 where the first dual layer is coated on a flexible plastic substrate containing transparent conducting electrodes followed by a coating or printing of transparent conducting electrodes on top of the first dual layer followed by coatings of the second dual layer followed by a coating or printing of transparent conducting electrodes on top of the second dual layer, followed by coatings of the third dual layer follow by lamination of the top flexible substrate containing transparent conducting polymer electrodes.
14. A device as claimed in Claim 12 where an isolation layer is coated or laminated before and after each coating or printing of transparent conductors.
15. A device as claimed in Claim 12 where the first dual layer is coated on a flexible plastic substrate containing transparent conducting electrodes followed by lamination of a substrate with transparent conducting electrodes on both sides on top of the first dual layer followed by coatings of the second dual layer followed by followed by lamination of a substrate with transparent conducting electrodes on both sides on top of the second dual layer, followed by coatings of the third dual layer followed by lamination of the top flexible substrate containing transparent conducting polymer electrodes on the laminated side.
16. A device as claimed in Claim 12 consisting of a stack of three dual layers with one dual layer is reflective at red wavelengths, a second dual layer reflective at green wavelengths and a third reflective at blue wavelengths.
17. A device as claimed in Claim 12 where at least one of the dual layers in the stack reflects at infrared wavelengths.
18. A bistable reflective display device consisting of microencapsulated droplet dispersions of cholesteric liquid crystalline materials wherein the droplets are spherical in shape to broaden the reflection spectrum and result in a substantially achromatic appearance as well as provide a wide angle of view
19. A bistable reflective display device consisting of microencapsulated droplet dispersions of cholesteric liquid crystalline materials in which the droplets are flattened or elliptical in shape to enhance the circular polarization component as well as the brightness of the reflected light.

20. A dual layer bistable reflective display device as claimed in Claims 9 consisting of microencapsulated droplet dispersions of cholesteric liquid crystalline materials where the droplets in the lower layer of one handedness are nearly spherical in shape and the droplets in the upper layer of the other handedness are flattened to produce a display of enhanced brightness and wide view angle.
- 20.1A display device consisting of an encapsulated droplet dispersion layer such that a portion of the droplets in the said layer are large and non-spherical for increasing S3 of the reflected light and a portion of the droplets are smaller and spherical to increase the viewing angle.
- 20.2A display device as claimed in Claim 20.5 where multiple coatings or laminations of the encapsulated droplet dispersion layers are made such that each layer may have different pitch length cholesteric materials or different handedness liquid crystalline materials.
21. A display as claimed in Claim 20 where the droplet diameter in the upper layer is larger than the thickness of the film to provide a flattened droplet shape and the ratio of the droplet thickness to its radius is used to control the degree of circular polarization, brightness, spectral width and angle of view of the resulting device.
22. A bistable reflective display device consisting of microencapsulated droplet dispersions of cholesteric liquid crystalline materials wherein the droplets have polymer networks within them that are used to modify the texture of the liquid crystalline material therein.
23. A bistable reflective display device consisting of microencapsulated droplet dispersions of cholesteric liquid crystalline materials wherein a specific distribution of droplet sizes and shapes is present throughout where certain proportion of droplets may be circular and certain proportion may be flattened to gain both high polarization as well as good viewing angle.

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Figure 1

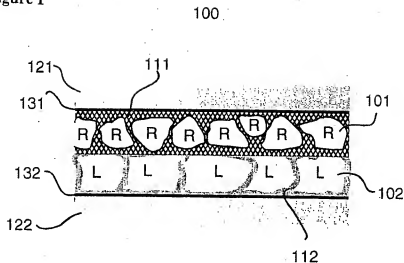


Fig. 1: Coated left (L) and right (R) handed cholesteric liquid crystalline materials between two substrates.

- 100: Bistable reflective display device
- 101: Droplets of cholesteric liquid crystal with right handed twist
- 102: Droplets of cholesteric liquid crystal with left handed twist
- 111: Encapsulating medium of cholesteric droplet dispersions of right handed twist
- 112: Encapsulating medium of cholesteric droplet dispersions of left handed twist
- 121: Upper substrate
- 122: Lower substrate
- 131: Transparent conducting electrodes of upper substrate
- 132: Transparent conducting electrodes of lower substrate

Figure 2

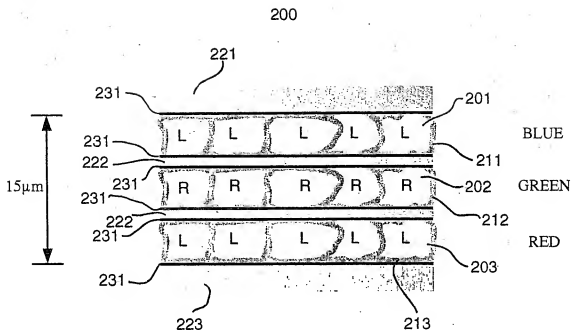


Fig. 2: R, G, and B layers stacked with inner separating substrates that have transparent conductors for electronic addressing. Each color layer has one coated cholesteric liquid crystalline layer.

- 200: Color reflective cholesteric display device
- 201: Cholesteric liquid crystal reflecting blue wavelength
- 202: Cholesteric liquid crystal reflecting green wavelength
- 203: Cholesteric liquid crystal reflecting red wavelength
- 211: Encapsulating medium of blue reflecting cholesteric droplet dispersion
- 212: Encapsulating medium of green reflecting cholesteric droplet dispersion
- 213: Encapsulating medium of red reflecting cholesteric droplet dispersion
- 221: Upper substrate
- 222: Intermediate substrates
- 223: Lower substrate
- 231: Transparent conducting electrodes

Figure 3

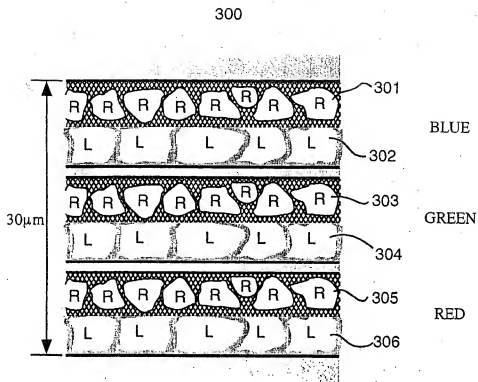


Fig. 3: R G and B layers stacked with inner separating substrates that have transparent conductors for electronic addressing. Each color layer has two (left and right) coated cholesteric liquid crystalline layers.

- 300: High brightness color reflective cholesteric display device
- 301: Cholesteric liquid crystal droplets of right handed twist reflective blue wavelength
- 302: Cholesteric liquid crystal droplets of left handed twist reflective blue wavelength
- 303: Cholesteric liquid crystal droplets of right handed twist reflective green wavelength
- 304: Cholesteric liquid crystal droplets of left handed twist reflective green wavelength
- 305: Cholesteric liquid crystal droplets of right handed twist reflective red wavelength
- 306: Cholesteric liquid crystal droplets of left handed twist reflective red wavelength